Physical-Chemical Crisis Indicators—Are There Any?

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ABSTRACT

The variation of pH, salinity, oxygen, and temperature is examined at 3 different locations in Chesapeake Bay. It is shown that the natural variation is so great that any attempt at delineating a dangerous environmental situation by the simple monitoring of any single parameter would probably not be successful. The concept of a station signature is introduced, where the ratio of extreme value to average value is plotted for a number of selected parameters. Since these ratios are non-dimensional, the relative variation of different parameters may be directly compared. Even though these signatures vary from station to station, the treatment of a series of different parameters together seems to hold more promise than that of one parameter by itself.

At this time there appears to be no magic black box which may be implemented to signal a crisis. Future work seems to be required in the areas of background determination for desired parameters, investigation of wide extreme persistence, effects of the same magnitude change in a particular water property at different levels of the same property, and the effect of a particular variation of one parameter at different levels of another seemingly independent parameter. It is suggested that the choice of crisis indicators should be determined by the particular ecological problem involved and will probably be different for different types of problems. Not only is it necessary to measure a series of parameters rather than 1 to indicate a crisis, but it also appears that data must be taken over a long enough period of time so that an average value for this period may be determined with which to compare the extreme values encountered.

In the previous papers in this symposium Chesapeake Bay has been described as a long, thin estuary with an average depth somewhat less than 10 m. This estuary is a very dynamic one, with "new" water being added from the ocean in addition to the fresh water input from the rivers. The river flow and the tidal forces drive the circulation of the Chesapeake Bay and produce the flow patterns that are found to exist. Contrary to some other types of arms of the sea, the physical processes of evaporation and wind seem to have a very small effect on the average flow conditions of the Bay, although they may have a strong short term effect.

In order to examine such a system and delineate any crisis indicators which may be utilized in environmental management, it appears necessary to determine first exactly what is meant by a crisis. Ostensibly a crisis is a situation wherein one or more water properties have reached such a value that the Bay is lessened in its usefulness for beneficial purposes or has reached a point where there is a public outcry. These 2 events may or may not be causally related. Generally speaking, there is an implication of some large variation from normal value of a particular parameter or group of parameters. However the definition is a rather subjective

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The author of many technical and scientific papers, Professor Williams has also written 3 books and has 2 more scheduled for publication in the near future. He has recently finished the design and development of a series of estuarine instruments suitable for high school use which is being marketed by a major instrument manufacturer. He is a member of a number of professional societies and is Vice President of the Estuarine Research Federation. His major research interests lie in the fields of underwater optics, instrumentation, and estuarine physics.

one because the words "large" and "normal" are somewhat difficult to characterize quantitatively. It is supposed that the term "large" will be defined in laboratory and field studies by the biologist who will determine the limits to which organisms may be stressed. The term "normal" will be discussed in this paper.

Stream Flow and Tidal Variations

The natural variation of most measureable parameters in Chesapeake Bay is very large. An excellent example of this is involved with the 2 driving forces mentioned previously as being responsible for the flow patterns found in Chesapeake Bay. Fig. 1 shows a plot of monthly maximum and minimum values for the stream discharge of fresh water into Chesapeake Bay during the period 1951-1971. The numbers appearing at the ends of the vertical lines indicate the year in which these extreme values occured. It may be seen that the monthly maximum amount of fresh water discharged into Chesapeake Bay in 1958 is 30 times as great as the monthly minimum discharge in 1964. Even when comparing the maximum and minimum values experienced in 2 record years during the same month, a wide extreme is found. For example, in the month of April the maximum value is about 4 times as great as the minimum value, going from about 65,000 to about 240,000 ft^3/sec.

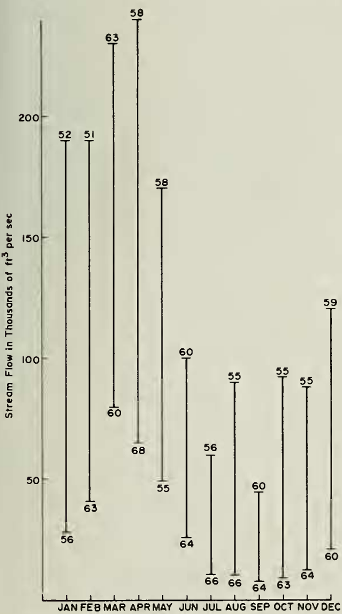


Fig. 1.–Stream discharge into Chesapeake Bay, 1951-71. Monthly ranges.

Tidal currents also vary rather markedly and within a relatively short period of time. This is demonstrated by the difference between the spring and neap situation. In Fig. 2 is shown a typical tidal current record for a point near the Chesapeake Bay Bridge in January, 1970. During the neap tide period the maximum tidal current range is about 1.5 knots (0.9 flood to 0.6 ebb). During the spring tide, following about 7 days later, the maximum range is about 2½ knots (1.3 knots maximum flood to 1.2 knots maximum ebb). Comparing these 2 extremes shows a ratio of 1.67, indicating that within a period of a week the tidal currents changed by almost 70%.

In addition to the extremes in water velocity due to the effect of the tide, the tide also moves a large volume of water past any given location. During 1 tidal cycle (about 12 hours, 25 minutes) of this spring tide, for example, a water mass almost 6 nautical mi long will have passed over an oyster on the bottom in this area. It is not surprising, then, that when various chemical and physical water properties are observed, they are found to vary a great deal.

Choice of Parameters and Stations

Four parameters are examined in this paper, but there are very many others that could have been included. A partial list of physical-chemical properties of interest in pollution studies might include the following: salinity, temperature, nitrate, hydrogen-sulphide, phosphate, pH, oxygen, turbidity, currents, water color, smell, taste, fluorescence, and radioactivity, in addition to fresh water inflow and the magnitude of

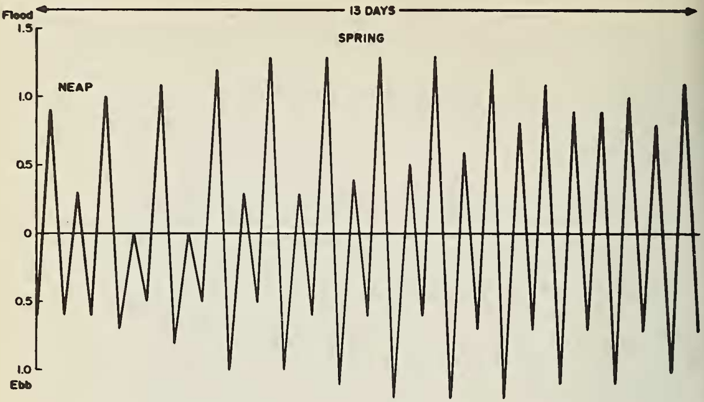


Fig. 2.–Typical tidal currents off Sandy Point over period of 13 days.

tidal currents. Many of these, such as color, smell, and taste, are difficult to measure quantitatively, and there is very little data available for others. For these 2 reasons only pH, salinity, dissolved oxygen, and temperature where chosen for this study. It was also felt that these 4 parameters are probably as characteristic of unspoiled environments as any others.

Most of the data used covered a period of about 10 years and were obtained from a total of 31 cruises occuring at more or less random intervals. Although these cruises were scattered throughout the 4 seasons (since the summer is more amenable to work at sea), somewhat more summertime data is available than for any of the other seasons.

Fig. 3 shows the location of 3 stations that were chosen to examine these data. One is located in the upper portion of the Bay about 4 mi north of the Chesapeake Bay bridge, 1 in the middle of the Bay very close to the mouth of the Patuxent River, and 1 in the lower portion of the Bay just opposite the entrance of the York River. Station 707ϕ and 904N both have a depth of about 12 m, while station 818N has a depth of about 14 m.

pH

The variation of pH at the 3 stations is shown in fig. 4. As before, the numbers appearing at the top of the vertical lines indicate the time at which the extreme value occurred, in this case the month, while the lines span the maximum and minimum values. For each station there is a surface (S) and bottom (B) data series that encompasses a 10-yr period, and for 1 of the stations there is another data series taken on cruises made about every 4-6 weeks for a period of 2 years. These latter data were obtained at the surface and at a depth of 10 M. Note that the pH varies markedly at all levels, but that the greatest range appears to be in the freshest water (Station 904N).

Salinity

A similar type of plot for salinity at these 3 stations is shown in fig. 5. As would be expected, stations closer to the ocean have higher average salinities, but note that the maximum surface salinity recorded at Station 904N is greater than the minimum surface salinity recorded at Station 707ϕ, about 120 mi south. An additional set of data is shown in this figure in that a 12-hr tidal cycle was examined with hourly read-

Fig. 3.—Location of Chesapeake Bay stations.

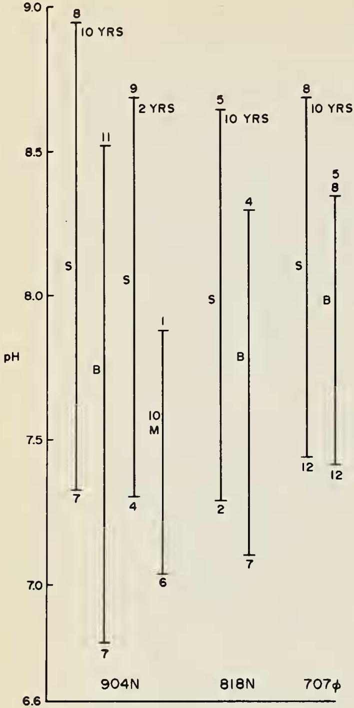


Fig. 4.—pH range of 3 stations in Chesapeake Bay.

ings taken at stations 818N and 707ϕ in the month of May. Even over a time period as small as 12 hours there is a salinity variation of as much as 2°/oo.

Dissolved Oxygen and Temperature

In fig. 6 is shown a similar type of variation for dissolved oxygen. Note that during the summer months the oxygen level on the bottom and even at a depth of 10 m is extremely low. There have been occasions where zero oxygen has been reported, although they did not appear in these sets of data.

Fig. 7 shows similar variations for temperature data including tidal cycle data taken at the same time as the salinity observations shown in fig. 5. Note that within a 12-hr period the surface temperature variation at station 707ϕ was about 3°C.

Not only does the local temperature vary markedly both seasonally and daily, but the variation in temperature throughout the Bay may also be very great. Fig. 8 shows the surface temperature taken during a cruise in August, 1961 over a distance of about 150 mi from the head of the Bay down to the ocean. The 3 stations considered in this study are pinpointed on the abscissa of the graph. There is a total range of temperature shown here of 8°, and even though these data were not taken simultaneously, they were obtained within a period of about 3 days. The anomalous blob of warm water appearing in the southern section of the Bay during this period is unexplained at this time, nor is it known how long this condition persisted.

The Station Signature

It appears from these data that any attempt to pinpoint a crisis on the basis of extreme values, of at least these 4 para-

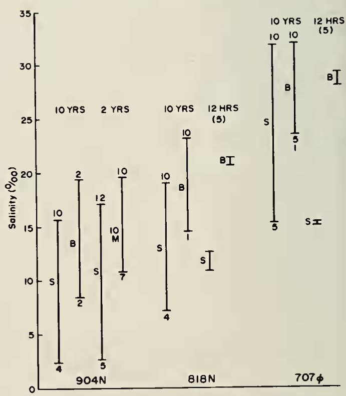


Fig. 5.—Salinity range at 3 stations in Chesapeake Bay.

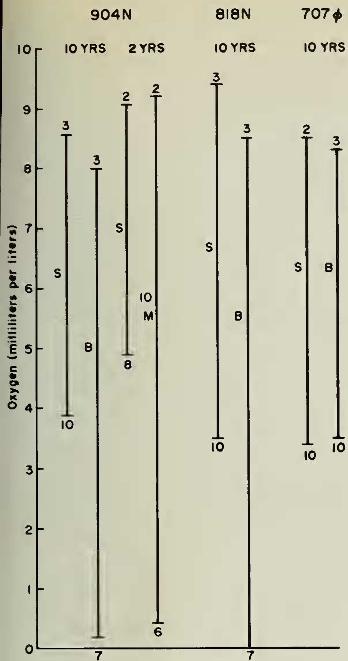


Fig. 6.—Dissolved oxygen range at 3 stations in Chesapeake Bay.

meters, would be somewhat useless since extreme values are not that uncommon under natural conditions. In order to classify more accurately the nature of unusual values it would seem somewhat more meaningful if the variations were compared to some measure of central tendency (an average of sorts) rather than examined as large or small independently. One possible method of doing this is to develop an extreme-to-average ratio for each parameter using all of the data at hand. This ratio seems highly useful if the assumption that something akin to the Weber-Fechner Law holds for the response of organisms to extreme changes in the environment. This law, although designed for the description of threshold values in perception, seems as though it might be applicable here.

The Weber-Fechner law states very simply that the minimum stimulus an organism can detect is related not only to the magnitude of the stimulus but also to the ambient level above which a response must be elicited. Thus, sounds very small in magnitude may be heard if the surroundings are very quiet, but in order to hear sounds in a very noisy atmosphere these minimum perceptible sounds must be quite large. It is suggested that this relationship be extended to the critical extremes of the environment. Thus we shall assume that small changes in the environment occurring at low ambient levels are just as dangerous as large changes imposed on high ambient levels. A salinity change of 1°/oo in an area where the average salinity is 3°/oo may very well be just as damaging to certain organisms, for example, as a salinity change of 10°/oo in an area where the salinity averages 30°/oo. It thus appears that the ratio of the extreme value to an average might be somewhat more meaningful than the extreme value by itself.

An average for some time period of the available data was calculated for each of the parameters, and the extreme values for these periods were then divided by the aver-

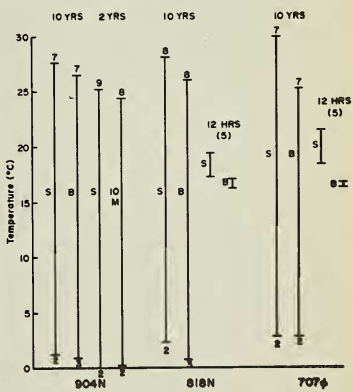


Fig. 7.—Temperature range at 3 stations in Chesapeake Bay.

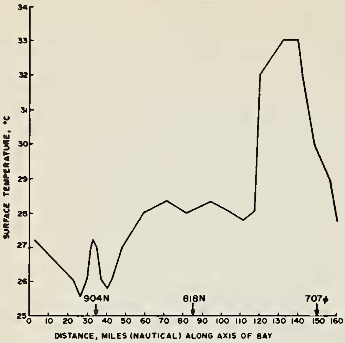


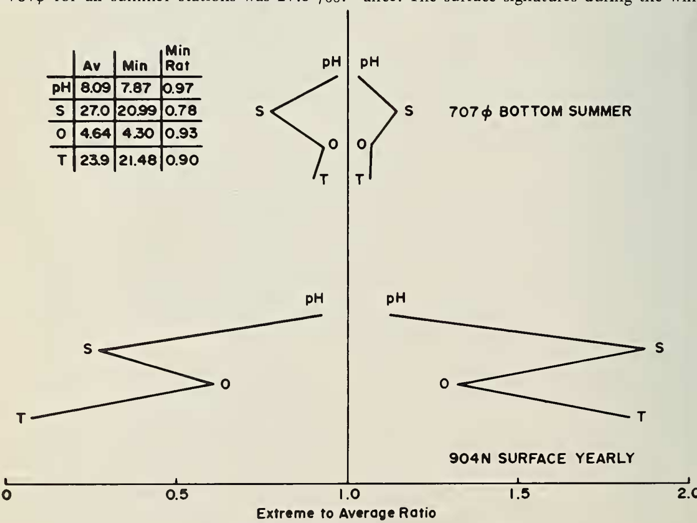
Fig. 8.—Surface temperatures along axis of Chesapeake Bay, August 1961.

ages. Fig. 9 shows the results for 2 particular locations. In the upper left corner a little table of the raw data is indicated to show the mechanism involved. For example, the average of salinity at the bottom of station 707ϕ for all summer stations was 27.0°/₀₀. The minimum value measured during the summer was 20.99, therefore the minimum ratio was 0.78. This is plotted at the top of fig. 9. The same type of calculation was made for both maximum and minimum values for all 4 parameters for Station 707ϕ on the bottom during the summer and Station 904N at the surface for all data available covering all 4 seasons. Since the ratios obtained in this manner are all nondimensional, it is now possible to compare variations in 1 water property with those of another, instead of considering a single property individually. These plots will be called station signatures; a few other examples are shown in the following figures.

Selected Station Signatures

In fig. 10 the surface signatures of Station 904N are shown for summer, winter, and yearly data. Seasonal changes in the total environment are quite evident.

The total environment of different stations during the same season is also at variance. The surface signatures during the win-



	Av	Min	Min Rat
pH	8.09	7.87	0.97
S	27.0	20.99	0.78
O	4.64	4.30	0.93
T	23.9	21.48	0.90

Fig. 9.—Two contrasting signatures, Chesapeake Bay.

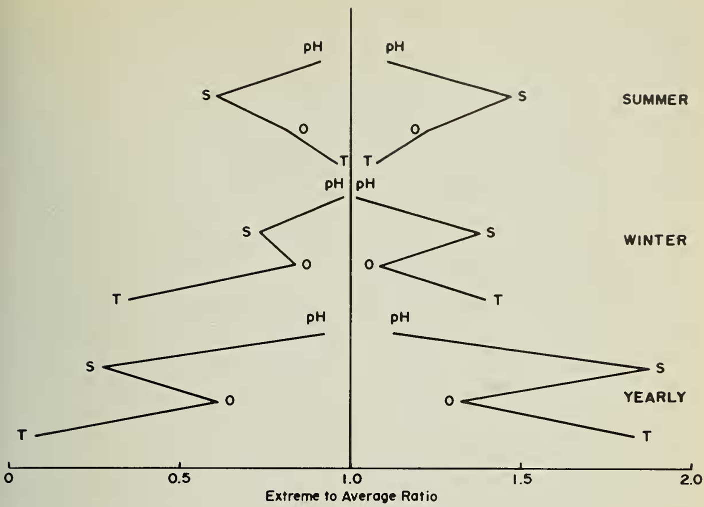


Fig. 10.—904N surface signatures.

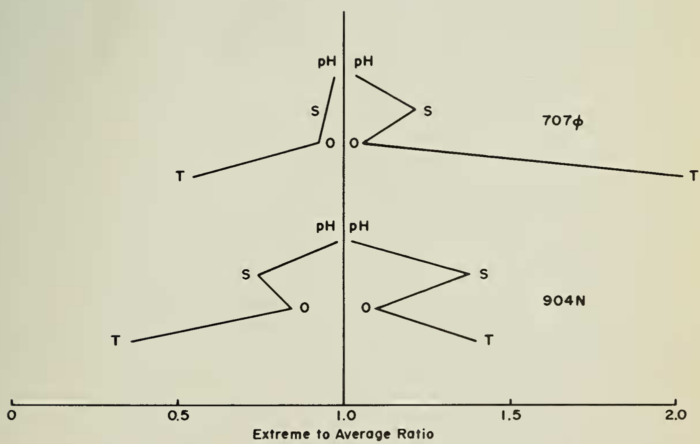


Fig. 11.—Surface winter signatures, Chesapeake Bay.

ter at 2 stations widely separated in Chesapeake Bay are shown in fig. 11, and although they are unique, similarities may be identified. In fig. 12 are shown 2 signatures for bottom conditions during the summer at Stations 707ϕ and 904N, and it may be seen that again there is a marked contrast. At Station 904N the oxygen protion of the signature is markedly different than it is at 707ϕ, although the other 3 parameters seem to have about the same general coordinates.

Fig. 13 shows both surface and bottom conditions at Station 904N during the summer. Even here it may be seen that the oxygen situation at the bottom of the station outweighs all other characteristics and lends the characteristic shape to the signature. One advantage of this presentation seems to be that a particular parameter is highlighted when it has a large effect on the environment, as oxygen does in this case.

From these data it seems that at this time it is not possible to implant a magic box in Chesapeake Bay that will automatically signal an alarm whenever a crisis appears. Part of the problem is involved with the previous discussion indicating that parameters are very variable, but another portion of the problem is involved with the fact that for each particular environmental situation there are different physical-chemical parameters to be considered. Just which of the various water properties are of major import is a management decision that is hopefully based on both laboratory and field data.

Since each parameter varies in a different manner at each location, the signature concept appears very desirable. However there is a major disadvantage in that for each signature large amounts of data are required for each depth, each season, and each stage of the tide. There seems to be no easy out.

Future Research

The suggestion for employing station signatures is one based on very preliminary data and will certainly require a great deal of exploration to validate not only the concept of the signature but also the concept of the greater validity of the extreme to average ratio as compared with the absolute value. It is suggested then that future research should fall into 4 general areas:

- The first of these would be determination of background information for the desired parameters in much greater detail than is presently available.
- The second area is the investigation of the persistence of wide extremes of particular parameters and their effects on various organisms.

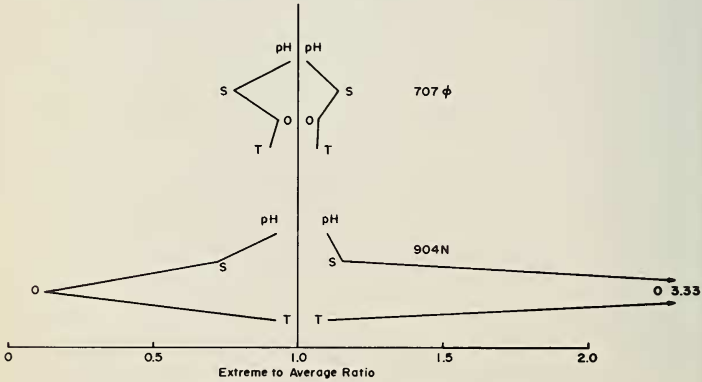


Fig. 12.—Bottom summer signatures, Chesapeake Bay.

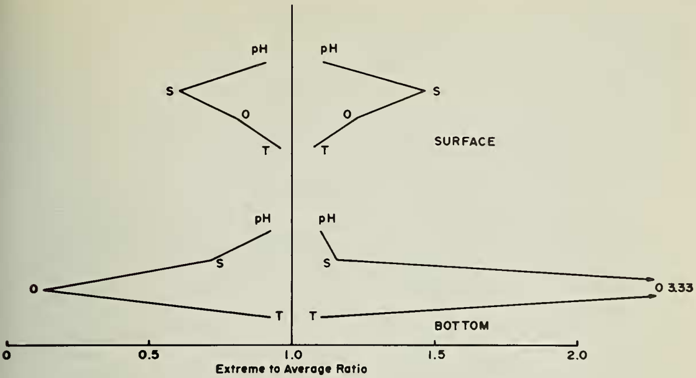


Fig. 13.—904N summer signatures.

• Third, it is suggested that investigation be made of the effects of the variation of 1 parameter on an organism when the ambient level of that parameter is changed. It would be expected, for example, that a rapid change of 5°C would be somewhat more noticable to an organism if this occurred at an average temperature of 1° as compared to this change occuring at a temperature of 20°. Investigations of this nature would determine the validity of the utilization of the extreme-to-average ratio.

• Lastly, it is suggested that research is required into the effects of variation of 1 parameter at different levels of another. This, of course, is an extremely complex procedure requiring a great deal of experiment, and it is an area in which very little work has been done. Since the natural environment exhibits such marked changes in so many parameters, a knowledge of the response of organisms to variations of 1 water property at different levels of another should be of extreme importance.